Ontario

Ministry of
Municipal Affairs
and Housing

TECHNICAL SERVICES DIVISION
RESEARCH & DEVELOPMENT SECTION

CONVENTIONAL FLAT ROOFS
ROOFING REPORT

Prepared for

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by

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and

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Maintenance Engineering Section

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INTRODUCTION

Apartment flat roof construction and its subsequent maintenance represents a large financial commitment for the building owner. Apartment roofs generally represent 3% to 5% of the initial total cost of the building.[1] Replacement of large sections of roof will also be a major cash outlay sufficient to cause financial hardship for building owners, especially if failure occurs early within the expected life of the roof.

Roof failure, as illustrated by moisture penetration can lead to "deterioration of roofing materials and destroy the effectiveness of insulation", to say nothing of the potential damage to building contents and inconvenience.[2] In the interest of maintaining good roof performance, experience of the past can aid in formulating repair and maintenance approaches which will protect the original investments and lessen repair costs.

The goal of roof installations is to provide weather-proof performance over a reasonable time span, usually quoted as a period of 20 years. Deterioration due to natural aging, building movement and roof traffic can be controlled by proper design, construction and maintenance of the roof. Minimal maintenance, shoddy construction and inadequate drainage often prevent the roof from performing satisfactorily. On existing roofs only a proper maintenance program can be instrumental in prolonging the life span of a roof.

[1] Marsden, R., Personal Contact, Ontario Ministry of Municipal Affairs and Housing, (1982).

[2] Link, R.E. Jr., "Airborne Thermal Infrared and Nuclear Meter Systems for Detecting Roof Moisture", U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, p.9.

The principal objective of this study then is to establish cost effective means of maintaining flat roofs and extending their service lives.

PROBLEM

The impetus for this roofing study lies in the poor performance of flat roofs owned by the Ontario Housing Corporation and similar experiences in the private sector. The responsibility for poor performance must be shared by the roof designer, roofing contractor and building owner. O.H.C.'s experience is a case in point.

Flat roofs have demonstrated an average in service life of 15 to 20 years.[3] Cadillac Fairview and O.H.C., for example, have had flat roofs that performed satisfactorily for up to 24 years.[4] Excluding these exceptions, O.H.C.'s flat roofs have a service life of 9 to 13 years, and thus do not live up to the life expectancies established by the roofing industry.

Roof failure not only decreases the life of the roof, but also affects the performance of roof insulation. The thermal resistance ("R" value) of dry insulation can decrease substantially when fully saturated. This reduction in thermal resistance places greater demands on a building's heating/cooling systems. Appendix IV outlines a typical scenario surrounding the diseconomies associated with wet roof insulation.

[3] Ashby, D. et al., Personal Contact, Tremco Canada, (1982)

[4] Clark, D., Roofing Study, Cadillac Fairview Residential Management, (1979) p.1.

O.H.C. has tried to remedy their flat roofing problems by undertaking a modernization programme which repairs/replaces damaged flat roofs. Replacement costs are site specific, but generally run in the neighbourhood of $\$29.06/m^2$ ($\$2.70/ft^2$)(1981). Comparable work done in the mid-seventies would have cost approximately $\$18.30/m^2$ ($\$1.70/ft^2$). If replacement is undertaken, O.H.C. will be forced to accept these ongoing and escalating costs unless a different approach is undertaken. Cost savings can be achieved through investment in planned/routine maintenance programmes.

Closer analysis of roof failures has identified some and can identify more areas which are chronic sources of roof problems. The majority (80%) of moisture penetration points are closely related with items such as: through roof fixtures, flashing failures, roof traffic and accidents.[5]

Armed with this type of specific knowledge and by initiating better methods of roof repair, cost effective approaches for maintaining flat roofs and extending their service lives can be established.

5 Steeves, D.M., Personal Contact, A-Tech Canada, (1982).

FINDINGS

The complexity of flat roofing systems demands varied solutions to treat the different stages of deterioration. The approach to this is essentially a 3-tiered response to roof deterioration and involves maintenance, repair and replacement.

Flat roof maintenance encompasses all planned/routine tasks necessary to keep the roof in working order and thus prevent moisture penetration. Identifying problem areas and ensuring that they receive regular attention is important. When these problem areas are identified, they should be inspected frequently and efforts made to keep them functioning properly as a result of that inspection. Many of the tasks will involve caulking/ sealing as part of a planned routine. The assessment of this routine indicates savings of 13% to 27% if the roof lasts for 20 years, and greater savings can be achieved if roofs last beyond that time limit. For detail review see Appendix II. A planned/routine maintenance program is outlined in Appendix III.

It has been O.H.C.'s experience that through the roof fixtures and attendant flashings, flashings in general and areas of regular roof traffic constitute the major source areas of moisture penetration. Roof areas, especially those characterized as a potential "problem", should receive attention during inspection. Maintenance programs should be undertaken, requiring frequent recaulking and resealing of all areas that fail frequently, as a general practice. This will by itself increase the life of the roof substantially by making certain that those parts of the roof that have a shorter life span than the rest of the roof are rejuvenated before they can contribute to roof damage or total roof failure.

In the event of further deterioration or mishap, roof repair may become necessary. Much of the work which is now relegated to repair ostensibly would not develop if planned maintenance was instituted. Repair consists of all non-routine services, short of wholesale replacement, contracted to improve or restore the moisture prevention characteristics of the roof. Repair of flat roofs includes draining, sectional replacement, resaturation, regravelling, reflashing and venting. Roof draining and venting are explained further in Appendix V.

Where roof conditions deteriorate to the point where there is not any value keeping the existing roof intact, tear off and replacement may become the only alternative. This is absolutely the last resort and should only be undertaken where the insulation/felts/membrane is/are deemed unsatisfactory. A judgement of this sort should be made on the basis of an assessment of the moisture content of the roofing and the serviceability of roofing components.

ASSESSMENT OF ROOF DAMAGE

The extent of damaged roof should be accurately determined prior to considering either repair or replacement of the roof. Currently, there are sophisticated instruments that can supplement visual inspection in determining the moisture content of the roofing system and thus the extent and severity of damage. If used properly, these state-of-the-art techniques can provide additional information which properly interpreted will indicate where the problems lie and therefore, in the long run, economize on repair or replacement cost.

ROOF TESTING

Moisture metering devices come in destructive and non-destructive forms. The accepted destructive devices

include the resistance probe and the cut test (gravimetric method). The non-destructive instruments involve electrical capacitance, nuclear radioisotopic and infrared thermography.

The destructive techniques share some serious drawbacks. All entail point measurements hence, the information provided by each test is for that specific test area only, there is no information regarding the extent of the damaged area. Furthermore, roof areas tested with these techniques must be repaired following their use. Additional tests effectively reduce the impermeable nature of the membrane.

Non-destructive techniques can provide information on whether moisture is present in the roof, the amount of moisture present, and the extent of the area affected.[6] These techniques are preferred as they generally do not contribute to further membrane damage and determine the location and extent of moisture invasion better. These non-destructive techniques have been employed in roof moisture detection since the early '70's.

Results of a recent National Bureau of Standards report have suggested that the nuclear radioisotopic equipment represents the most reliable non-destructive moisture metering system available. Thermal infrared devices were considered comparable however, assessment was based on limited applications. Electrical capacitance was judged less reliable than either the nuclear radio-isotopic or thermal infrared systems. Greater detail on roof moisture meters can be found in Appendix VI.

[6] Jenkins, D.R., Mathey, R.G., Knab, L.I., Moisture Detection in Roofing by Non-Destructive Means, A-State-of-the-Art-Survey, Technical Note No. 1146, Centre for Building Technology, National Engineering Laboratory, National Bureau of Standards, Washington, D.C., U.S.A., (July 1981) p.8

O.H.C.'s experience with moisture metering is largely based on nuclear radioisotopic analysis. A number of buildings in the metropolitan region were surveyed by this method in 1976. In a sample of these buildings the service lives of these roofs were prolonged and wholesale replacement deferred as an indirect result of moisture metering. The cost savings attributable to moisture metering in this same sample was 65%. The data assembled on the sample of moisture metered roofs is contained in Appendix VII.

Roof Design

Planned maintenance does not mean that roof replacement is eliminated, but deferred until the normal life expectancy of the roof is realized. A fundamental flaw in flat roof design is that they do not shed water; they retain, drain or pond it. Moisture penetration in flat roofs is therefore likely. Planned/routine maintenance is only an interim solution to the problem.

An attractive way of alleviating most of the preceding problems is to phase-out the flat roof. The alternatives usually involve introducing slope to flat roofs. Sloping the upper surface can be achieved by manipulating 4 variables.[7]

a) tilting the structural deck
b) sloping the deck surface
c) sloping the deck fill
d) sloped insulation surface

The minimum slope for effective roof drainage is 1:50. The slope of a roof must be sufficient to overcome

[7] Baker, M.C., Roofs, National Research Council of Canada, Multiscience Publications Ltd., Montreal, Canada, (1982) p. 190.

construction inaccuracies, material surface friction and deck deflection. Preference, including the foregoing suggestions, should be given to those features which uphold the requirements of a good roof as identified in Appendix VII.

Industry sources claim the life span of conventional flat roofing is 15 to 20 years.[8] Those roofs with slope have life expectancies which are substantially longer. The decision to remain with conventional flat roofing will be inviting future problems. However, problems will arise on any roof, design, emphasizing a sloped roof surface will only make roof repair or maintenance easier. Roof life expectancies are detailed in Appendix I.

[8] Ashby, D., et al., Personal Contact, Tremco Canada (1982)

APPENDIX I

ROOF LIFE

Industry sources recommend that flat roofs should have a service life of 15 to 20 years.[35] Cadillac Fairview has experienced better than average roof performance with many of their roofs performing satisfactorily for up to 24 years.[36] O.H.C. has a few roofs which have lasted a fairly long time, but buildings constructed in the 1960's and 70's have experienced worse than average roof performance.

The life expectancy statistics of O.H.C. roofs are based on the following data of 36 roofs.

SUBJECT NUMBER AND ADDRESS	YEAR ROOF BUILT AND/OR REPLACED	YEAR ROOF REPLACED	AGE OF ROOF WHEN REPLACED
OH 86 Phin Park	1959	1981	22
OH 85 Sumach St.	1970	1979	9
OH 69 St. Clair Ave. E.	1968	1980	12
OH 91 Queen St. E.	1963	1979	16
OH 91 Queen St. E.	1963	1979	16
OH 38 Edgewood Ave.	1956	1979	23
OH 38 Edgewood Ave.	1956	1979	23
OH 113 Gordon Ridge Place	1973	1981	8
OH 101 B Kingston Road	1973	1981	8
OH 101 C Kingston Road	1973	1981	8

[35] Ashby, D., et al, Personal Contact, Tremco Canada (1982)

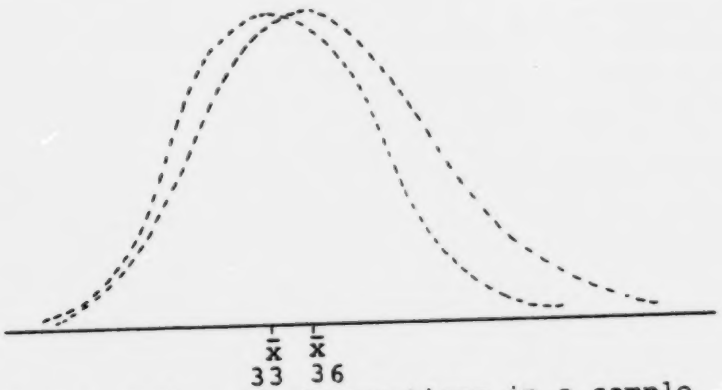
[36] Clark, D., Roofing Study, Cadillac Fairview Residential Management (1979) p. 6.

SUBJECT NUMBER AND ADDRESS	YEAR ROOF BUILT AND/OR REPLACED	YEAR ROOF REPLACED	AGE OF ROOF WHEN REPLACED
OH 101 E Kingston Road	1973	1981	8
OH 101 F Kingston Road	1973	1981	8
OH 101 G Kingston Road	1973	1980	7
OH 60 Eglinton Ave. E.	1965	1980	15
OH 116 Birchmount Ave.	1972	1980	8
OH 73 Kennedy Road	1969	1979	10
OH 80 Lawrence Ave. E.	1970	1975	5
OH 80 Lawrence Ave. E.	1970	1980	10
OH 32 Augusta Square	1968	1980	12
OH 29 Duncan Woods Dr.	1966	1981	15
OH 25 Shoreham Dr.	1969	1979	10
OH 25 Driftwood Ave.	1970	1978	8
OH 39 Roywood Dr.	1962	1974	12
OH 80 Lawrence Ave. E.	1970	1979	9
OH 46 Decham Pk.	1968	1980	12
OH 84 Falstaff	1971	1979	8
OH 61 Jane Street	1968	1980	12
OH 27 Humber Blvd.	1968	1980	12
OH 112 Needle Fairway	1971	1979	8
OH 51 Sentinel Road	1966	1979	13

SUBJECT NUMBER AND ADDRESS	YEAR ROOF BUILT AND/OR REPLACED	YEAR ROOF REPLACED	AGE OF ROOF WHEN REPLACED
OH 85 River St.	1959	1971	12
OH 12 Sheppard Ave.	1963	1981	18
OH 4 (A,B,C,) Yellowstone	1965	1981	16
OH 118 Victoria Park	1972	1981	9
OH 85 River St.	1959	1970	11
OH 63 Lumsden Ave.	1969	1976	7

The data was broken down into 2 sample groups to clarify the influence of the unusually old roofs on the original sample of 36. The mean scores for the original and modified samples are 11.47 and 10.45 years respectively. A year decrease in average roof life expectancy resulted when the 3 oldest roofs were removed from the sample as demonstrated on the following page.

n	=	36	n	=	33
Σx^2	=	5624	Σx^2	=	4082
$\bar{x}$	=	11.47	$\bar{x}$	=	10.45
s^2	=	20.72	s^2	=	10.28
s	=	4.55	s	=	3.21



WHERE: n is the number of observations in a sample

Σx is the summation of observations in the sample

Σx^2 is the summation of the squares of the observations in the sample.

$\bar{X}$ is the mean of the sample

s^2 is the estimate of the population variance $\frac{\Sigma (x-\bar{x})^2}{n-1}$

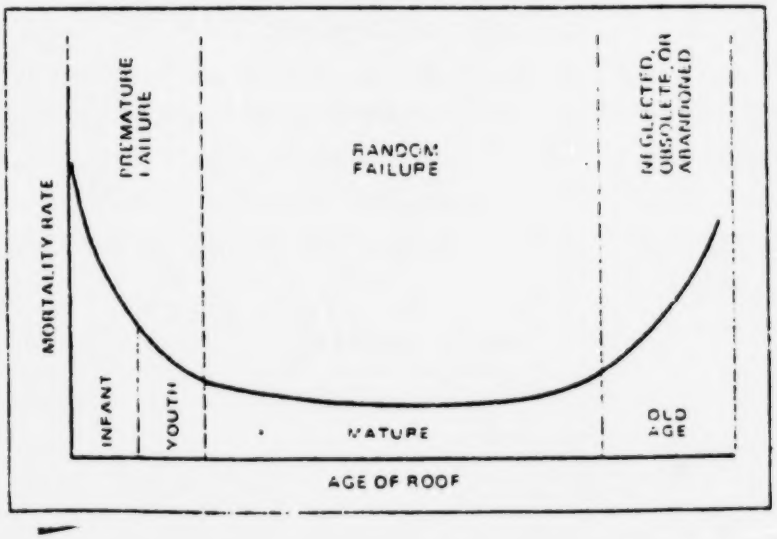
S is the estimate of the population standard deviation.

The variance and standard deviation of the samples indicated that the modified sample shows less variability hence greater homogeneity than the original sample. The 2 bell curves illustrate the distributions for the original and modified samples and should substantiate statistical interpretations.

Failure Rate Curve:

It has been proposed in recent literature that flat roof life expectancy can be evaluated utilizing a failure rate curve.

The roof failure rate curve is analogous to actuarial curves. This curve suggests that the frequency of roof failure is highest for those roofs between the ages of 0 to 5 and beyond 15 years. In between these extremes, roof failure is largely by random occurrence as seen in the diagram below.

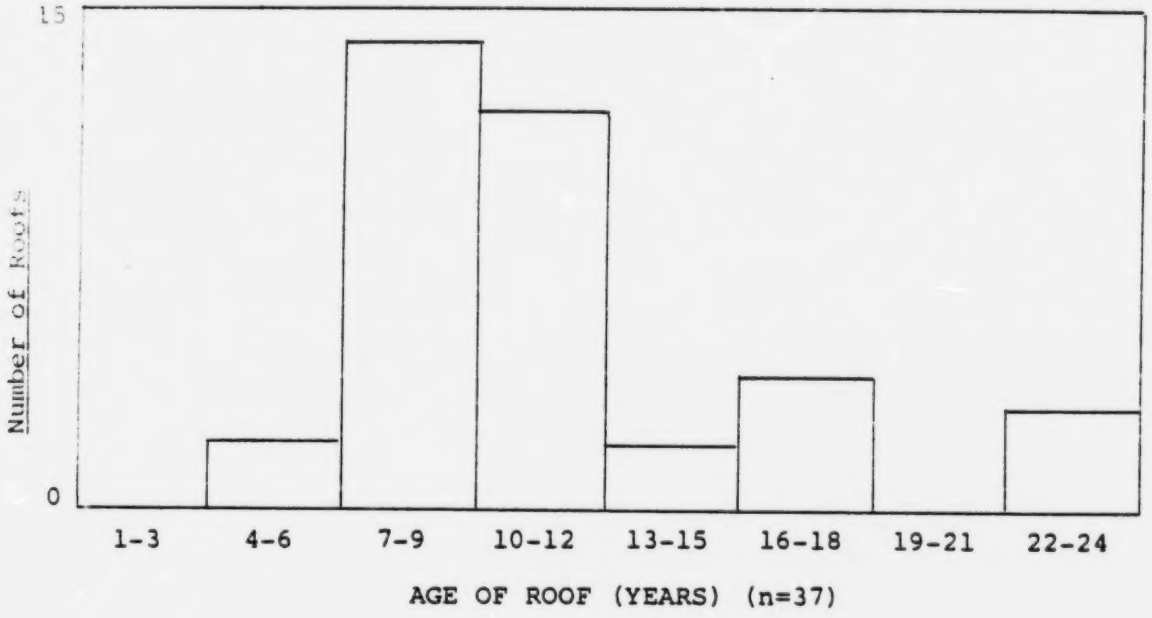


Roof failure can be defined as the deterioration of one or more roofing components such that they will no longer adequately protect the building contents. Failure early in the roof's service life can usually be attributed to poor application or improper material specification. Roof failure during the mature years is generally prompted by roof related accidents or unusually high volumes of roof traffic. In the event a roof survives to "old age" failure can usually be traced to natural processes.

When compared to the previously mentioned roof failure rate curve, O.H.C.'s most recent flat roof performance is inferior to reliable industry standards. Life expectancies seem positively skewed towards premature failure.

[37] Webb, L., "Figuring the Real Cost of Roof Maintenance," Manual: Roofing Industry Educational Institute, Englewood Colorado, U.S.A. (1977).

This situation can be more clearly realized in the following frequency histogram.



It should be recognized that this increased incidence of premature failure is a recent phenomenon. O.H.C. roof service lives include older roofs of 22 to 23 years. However, the bulk of O.H.C. observations lie in the range from 7 to 12 years.

APPENDIX II

ROOF MAINTENANCE COST EVALUATION

Future value served as the statistical vehicle for the comparison between planned/routine maintenance and minimal maintenance. Critical assumptions were made based on roofing industry cost estimates for minimal and planned maintenance programs, the public sector tax scenario and flat roof life expectancy figures. Together they represent a fairly accurate assessment of the components in the decision to repair or replace a roof, and are as follows:

a) future value = present value x $(1+i)^n$

b) minimal maintenance represents 1% to 2.5% per annum of the original roof replacement cost (29¢/m^2 (2.7¢/ft^2) to 73¢/m^2 (6.8¢/ft^2) 1981 dollars.

c) planned/routine maintenance represents 3% to 5% per annum of the original roof replacement cost (1.16/m^2 (10.8¢/ft^2) to 1.45/m^2 (13.5¢/ft^2) 1981 dollars.

d) roof replacement cost (Remove and replace) is \$29.06/m^2 (\$2.70/ft^2) 1981 dollars.

e) roof area is 1374.96m^2 (14,800/ft^2).

f) federal/provincial taxes, including capital cost allowance were omitted and municipal taxes held constant in this example.

g) inflation is compounded annually at "i" per cent.

h) a roof without planned maintenance will last a minimum of 10 years and be replaced on the 11th year. The roof will then be scheduled for replacement on the 21st year.

i) a roof with planned maintenance will last a minimum of 20 years and be scheduled for replacement only when it becomes necessary or on the 21st year.

j) roof replacement cost on the 11th year is calculated as the future value of $40,000.00(1981) adjusted as per inflation rate.

The results of the comparison appear below:

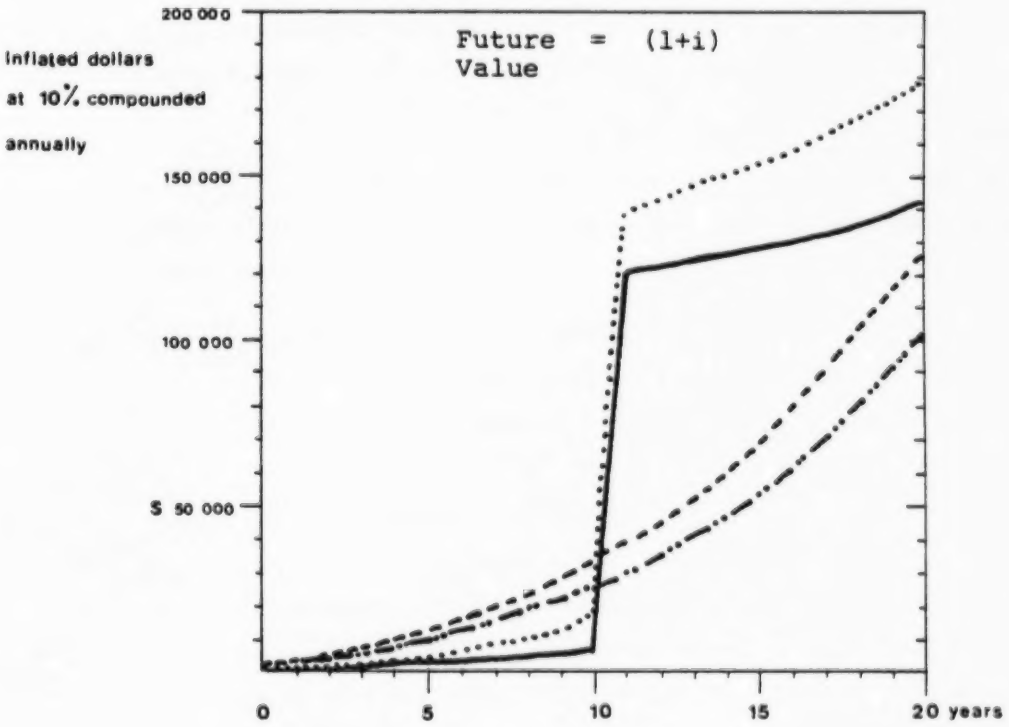
MINIMAL MAINTENANCE PROGRAMME (for 20 years):

Average Inflation Compounded Annually	Total Future Value 1% ($400.00) + replacement cost, 11th yr.	Total Future Value 2.5% ($1000.00) +replacement cost, 11th yr.
2	59,135.97	73,259.95
4	73,331.90	90,989.73
6	90,757.77	113,014.45
8	112,100.52	140,355.27
10	138,179.76	174,269.39
12	170,972.27	216,362.18
16	256,169.31	333,403.25
18	313,774.01	413,881.08
20	383,838.19	513,795.52

PLANNED MAINTENANCE PROGRAMME (for 20 years):

Average Inflation Compounded Annually	Total Future Value 4.0% ($1600.00)	Total Future Value 5.0% ($2000.00)
2	39,653.33	49,566.63
4	49,550.72	61,938.41
6	62,388.38	77,985.47
8	79,076.67	98,845.85
10	100,834.02	126,005.01
12	129,118.01	161,397.46
16	214,144.81	267,581.00
18	276,833.62	346,042.03
20	358,440.95	448,051.19

The calculations indicate that planned maintenance programmes are cost beneficial. Real savings of 13% to 27% over minimal maintenance are possible with planned maintenance, given inflation rates of 10% to 20%. Graphically, this potential for cost savings is demonstrated below, assuming 10% inflation.



(2.5%) ($1,000.00) Minimal Maintenance Cost
(1.0%) ($400.00) Minimal Maintenance Cost
(5.0%) ($2,000.00) Planned/Routine Maintenance Cost
(4.0%) ($1,600.00) Planned/Routine Maintenance Cost

Proponents of planned/routine maintenance argue that the roof, if properly maintained, should last the life of the building.[38] However, even if roof replacement is considered on the 21st year, the economy of planned/routine maintenance prevails.

38 Sobkowich, V., "Faulty Roofs and Professional Liability", The Canadian Architect, Southam Business Publications, Toronto, Canada, (October 1977)

APPENDIX III

PLANNED/ROUTINE MAINTENANCE PROGRAMME

The basis of a planned/routine maintenance programme has been adopted from the recommendations made by various moisture metering services and from other sources in the roofing industry. Any programme must be flexible with respect to the timing of specific tasks as the environmental conditions and/or available equipment could constrain work, but should at least encompass the following points:

A) Organize records so as to establish the complete roof history including all additions/alterations/repair to roof system or surface/subsurface equipment and keep them up to date.

B) (i) Arrange a visual inspection of the roof on a minimum bi-annual basis (i.e. spring and fall), ideally on a seasonal basis (i.e. winter, spring, summer, fall). All records of past and present visual inspections should be kept.

(ii) Roof inspections by non-destructive means should supplement visual inspections at an interval of once every 3 to 4 years. Again all records of past and present moisture metering surveys should be kept.

C) The visual inspection should concentrate on known roof problem areas and ensure these same areas are well maintained.

D) Routine maintenance tasks and their frequency should be established to assure that the roof is continually rejuvenated.

E) In the event roof repair/replacement is deemed necessary, specifications should be prepared for the work based on moisture metering information together with visual inspections.

APPENDIX IV

ROOF INSULATION PERFORMANCE

Wet roof insulation is a major source of heat loss and gain in buildings. The additional cost of operating a building and its heating and cooling system with wet insulation can be significant. Ensuring that roof insulation is dry can lead to a longer roof service life, better roof performance and a more economically operated building.

The impact of wet and dry insulation on energy consumption can be gauged by measuring or calculating the amount of heat which is transmitted through $1ft^2$ of 1 inch material in 1 hour, when there is a temperature difference across the 2 surfaces of the material. In the following scenario energy loss through wet and dry roof insulation as well as cost and energy savings attributable to dry insulation will be calculated using:

a) Kw/ft^2/season (electricity)
b) $/$ft^2$/season ($/m^2/season)

Factors:

Thermal conductivity (K) of fibreboard (by extrapolation)
K = .84 (wet) 25% water content by volume.
K = .60 (dry, high ambient humidity) 13% water content by volume.
K = .50 (dry, average ambient humidity) 8% water content by volume.
Electricity cost - 3.46¢/Kw = $1.01/therm.
Therm (energy) - 100,000 B.T.U. = 29.3 Kw.
1 Kw = 3413 B.T.U.

EXAMPLE 1 - Dry Condition

Average Toronto temperature over heating season $37.6^{\circ}F(3.1^{\circ}C)$.
Inside ceiling temperature $75^{\circ}F$ $(23.8^{\circ}C)$.
Heating season (Oct. 1 - Apr. 31) = 212 days.
$.10 \times 37.4 = 3.74$ B.T.U./ft^2/hr
$3.74 \times 24 \times 212 = 19{,}029.12$ B.T.U./ft^2hr.
$19{,}029.12/3413 = 5.58$ Kw/ft^2/season
$19{,}029.12 \times \$1.01/100{,}000$ (B.T.U.) = 19.22¢/ft^2/season
(2.05/m^2/season)

EXAMPLE 2 - Wet Condition

In the second example the heat loss in terms of cost and energy consumption will be calculated based on the comparison of dry and wet fibreboard insulation. A "K" factor difference of .34 is calculated for fibreboard of 25% and 8% water content by volume.

$.84 - .5 = .34$

The temperature difference experienced between the interior and exterior of the roof is calculated using $75^{\circ}F$ (the assumed averages).

$75^{\circ}F - 37.6^{\circ}F = 37.4^{\circ}F$

The heat loss attributable to the condition of the insulation and temperature experienced is shown below:

$.34 \times 37.4 = 12.72$ B.T.U./ft^2/hr
$12.72 \times 212 = 69{,}719.36$ B.T.U./ft^2/hr
$64{,}719.36/3413 = 18.96$ Kw/ft^2/season
$64{,}719.36 \times \$1.01/100{,}000 = 65¢/ft^2$/season
(6.97/m^2/season)

Cost difference on average roof

On an average residential high rise roof of 15,000 ft^2 (1393.5 m^2) the economy of relatively dry versus wet insulation can be calculated on a seasonal basis.

a) 15,000 ft^2 (1393.5 m^2) (relatively dry roof) @ 19.22¢/ft^2/season = $2,850.00/season/83,700 Kw/season

b) 15,000 ft^2 (1393.5 m^2) (wet roof) @ 65¢/ft^2/season = $9,750.00/season/284,400 Kw/season.

The cost, $12,850 U.S. $9,750, and energy loss 83,700 Kw vs. 284,400 Kw for leaving a roof intact with 13% moisture content by volume, is dramatically less than the roof with 25% moisture content by volume. Energy loss and cost of the magnitude found in the examples can easily justify ongoing good roof maintenance to prevent moisture depredation over the life of the roof.

It must be emphasized that dry insulation is a relative term. The ambient environmental conditions must be considered before any true economy attributed to relatively dry insulation can be calculated. If the difference between the moisture contents of dry and wet insulation had been more pronounced, the energy and cost savings attributable to dry insulation would increase. As energy costs rise the potential for cost savings through maintaining the roof system becomes even more attractive.

APPENDIX V

ROOF DRAINING AND VENTING

Roof systems are subject to a great deal of external and internal pressure due to the presence of water. Water on the surface must be drained, water vapour within the system must be drained and/or vented. The main aspects of both drains and vents will be identified in the following paragraphs.

DRAINING:

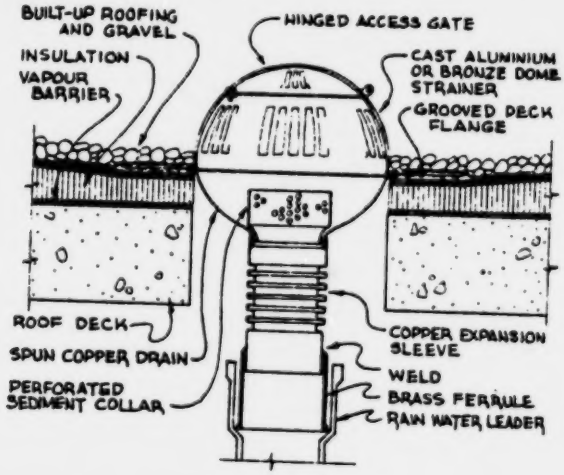
The common roof drain is a proven solution to removing water from the roof surface. However, they do have their drawbacks. They are most often integrated into the structural columns of buildings. Unfortunately, these drain locations are not the low points on the roof. The water on the roof surface therefore, cannot readily reach each drain provided. It has been proposed in many quarters that these drains be moved from the columns to mid-span or especially to points where deck deflection is greatest, thus ensuring that water drainage does occur.

In addition, most drains feature some variety of screening to prevent gravel and other foreign material from entering and clogging the drainage system. This problem however, is not totally overcome by these provisions and requires regular attention by staff so as to ensure that these drains are and remain functional.

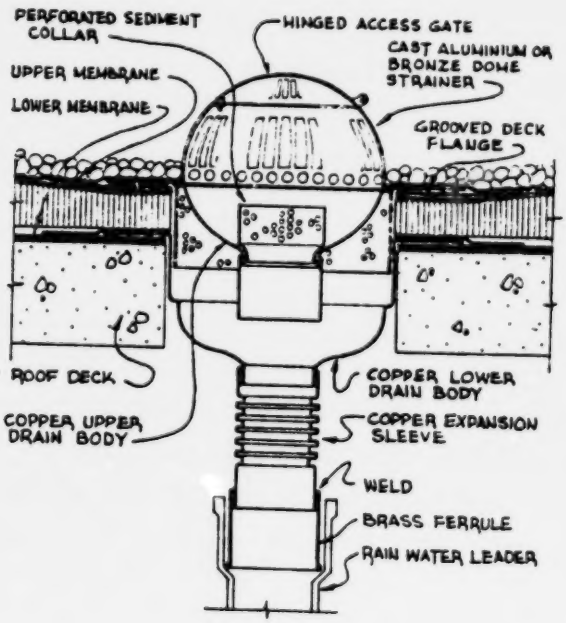
Finally, in the event rain water does make it to the drain, its movement may be further hampered by controls put on roof drains to limit storm water demands on the storm drainage system. In many municipalities control flow drains are mandatory to regulate the flow of rain water to the sewer. The use of control flow drains

also allows for the use of smaller diameter pipes and fittings, providing greater economy in construction but putting a burden on the roof by allowing water buildup.

Drains are manufactured in many forms. The single drain as pictured below, has been installed in the majority of flat roofs.[9]



Double membrane roof systems however, are more complex and require sub-surface drainage. Double drains were introduced to provide drainage and ventilation for double membrane roof systems as seen below.[10]



[9] Baker, M.C., Roots, National Research Council of Canada, Multiscience Publications Ltd., Montreal, Canada, (1982) p.245

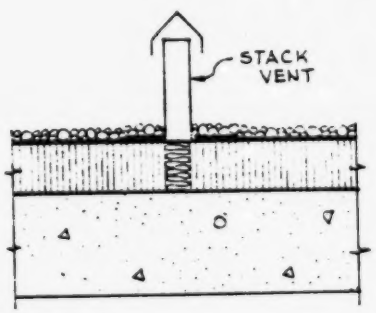
[10] Ibid, p.191

Integrating the double drain into the double membrane roofing system allows drainage of the upper and lower membrane as well as all contained materials. Double drains can also reduce the number of roof breather vents which lessen further roof penetrations and thus potential moisture penetration points.

VENTING

A roofing system will require venting to relieve internal roof pressure and/or accumulation of moisture vapour. Venting can be integrated into the roofing system from the outset, or as a remedial measure designed to alleviate moisture problems encountered later in the roof's service life. The venting can be provided through active and passive methods.

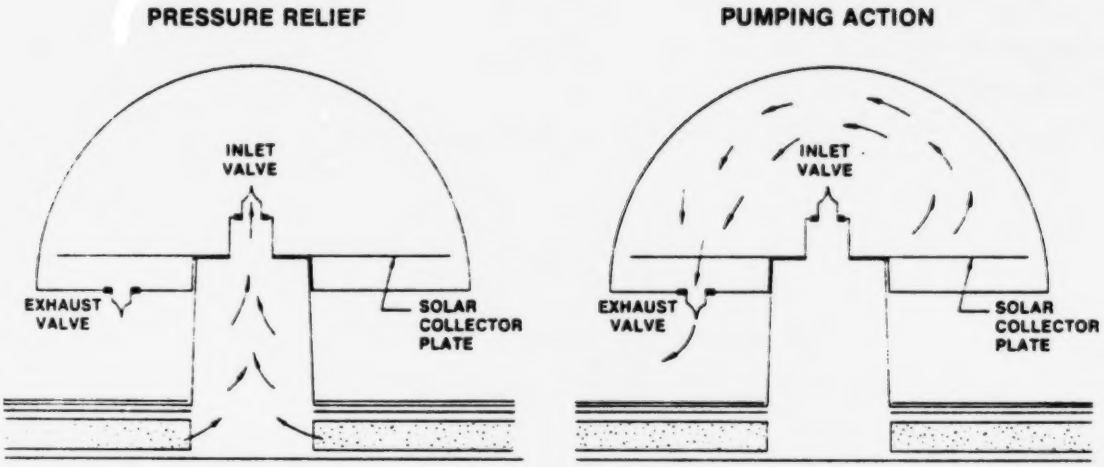
Breathers are passive forms of vents and can provide relief from internal roof pressure caused by the expansion of air and water vapour within the system. These vents usually consist of vertical pipes or stacks, open to the outside air, shielded from the rain by a cover and penetrating the roof membrane as shown below.[11]



[11] Ibid, p.192

Where rigid board type insulation is used, loose fill insulation may be substituted directly beneath the vent, to the depth of the roof deck, allowing for improved breathing. Breathers require 2 vents for every 1,000 ft^2 of roof to function properly. It has been found that the double drain in double membrane roof systems does perform as effectively as the conventional breather, and thus the roof requires fewer penetrations.

Active venting usually involves the use of the solar powered roof vent. These vents differ from the breather in that they actively create a pressure gradient, enhancing the escape of water vapour from the roofing system. The system and its principles are diagramed below.[12]



[12] Lexsuco, Information Bulletin, B.F. Goodrich Construction Products, Akron, Ohio, U.S.A. (1982)

The solar powered roof vent has proven comparatively expensive and prone to vandalism in certain accessible locations, yet its ability to vent wet insulation is substantially better than that of the passive breather vent, and could be an inexpensive solution to a roof which has some excess moisture.

Venting has an unrivalled ability to let roof systems breathe. It has been found though, that in many venting applications moisture penetration points have occurred due to shoddy installation. These same penetration points subsequently offset the benefits of the vent.

APPENDIX VI

METHODS OF ROOF DAMAGE ASSESSMENT

Moisture detection methods can dramatically reduce guesswork associated with flat roof repair or replacement. The most popular destructive and nondestructive techniques are reviewed from an essentially non-technical perspective. Two reports from the National Bureau of Standards "Laboratory Evaluation of Nondestructive Methods to Measure Moisture in Built-Up Roofing Systems" and "Moisture Detection in Roofing by Nondestructive Means, A State-of-the-Art Survey" will serve as the basis for description and evaluation of the nondestructive methods.

METHODS OF DAMAGE ASSESSMENT

Destructive Techniques

Cut test is perhaps the crudest destructive technique. A core sample is taken from the roof, placed immediately in an air tight container and transported to a lab where it is weighed before and after drying. The weight differential is attributable to the moisture content of the core sample.

Resistance probe is another relatively simple destructive device. A voltage is impressed between 2 prongs while the prongs are embedded in the roofing system, current is then measured based on wet and dry calibrations of the materials being inspected. Probes of this variety have been used for moisture detection in plaster, brick, concrete and soils.

Fibre optics, another destructive technique, has been used for roof moisture metering in Great Britain. This technique consists of an optical fibre and light source being inserted into a small hole in the roof system to facilitate visual inspection.

The effectiveness of the fibre optics for roof moisture metering has not been evaluated.

All destructive moisture detection devices share the same drawbacks. These techniques involve point measurements. The information provided by each test is for that specific test point only; there is no information regarding the extent of the damaged area. Test areas must be repaired following the completion of the test. Additional tests effectively reduce the impermeable nature of the membrane.

Nondestructive Techniques:

"Nondestructive techniques can provide information on whether moisture is present in the roof, the amount of moisture present and the extent of the area affected."[13] The application of nondestructive techniques can be universally adaptable. These methods, however, require careful evaluation and interpretation of the data collected.

Electrical capacitance equipment responds to the dielectric constant or loss factor of a material. The dielectric constant (K) is a measure of the ease with which an electrical field can be set up in a material. Dielectric loss factor ($\mathcal{E}$) is related to the energy lost in an alternating electrical field.[14] Moisture, if present in roof systems, is identified by dielectric constants in the neighbourhood of 80, whereas dry roofing materials are characterized by constants that range from 1 to 5.[15]

13 Jenkins, D.R., Mathey, R.G., Knab, L.K., Moisture Detection in Roofing by Nondestructive Means - A State-of-the-Art Survey, Technical Note No. 1146, Centre for Building Technology, National Engineering Laboratory, National Bureau of Standards, Washington, D.C., U.S.A., (July 1981) p.8.

14 Ibid, p.11

15 Ibid, p.11

The electrical capacitance device must first establish wet to dry threshold readings for particular roof systems.[16] This process usually involves a dry "baseline" reading obtained with the aid of coring. Experience with roofing systems is used to relate instrument readings to moisture content.[17] It is the relative difference between wet and dry readings that is significant.

Electrical capacitance instruments will exhibit a high dielectric constant where there is moisture in the roofing system. Irregularly distributed moisture in/on the roofing system can lead to electrical field distortions and cause unpredictable depth of penetration as well as errors in interpretation. These conditions can be further aggravated by surface gravel thickness. Readings then might not be representative of the moisture content of the roof system.

Nuclear radioisotopic equipment is the second nondestructive moisture meter to be considered. It relies on fast moving neutrons to penetrate the roof materials and collide with hydrogen nuclei. The detector of the nuclear meter in turn records the backscatter from these fast-turned-slow neutrons over a specified period of time.[18] Water in the roofing system represents a supply of hydrogen nuclei. There are also hydrogen nuclei in other composites as well (e.g. asphalt).

Nuclear meter readings can be influenced by surface gravel thickness, greater bitumen thickness, surface moisture and deck type. It is similar to the electrical capacitance method in that it is difficult to determine depth of penetratration.

[16] Ibid, p.15
[17] Ibid, p.15
[18] Ibid, p.21

There are indications that depth of penetration may depend on the total amount of hydrogen present. However, depth of penetration is usually sufficient to give a reading representative of the moisture content for the material tested.

Nuclear meters can cover on average, areas of $2ft^2$ ($0.1858\ m^2$) at each test measurement, and to an average depth of 8 inches (203 mm)[19]. Nuclear devices must be calibrated on wet and dry roofing materials to determine wet and dry threshold readings. Core samples can be taken to supplement/audit readings at various locations. The data that is collected is subjected to a substantial amount of analysis before delineating the roof moisture contours.

The electrical capacitance and nuclear radioisotopic moisture meters are point measuring devices. Both employ a grid system in roof moisture detection. The grid can range from 5 feet by 5 feet (1.524 m x 1.524 m) and up. This standard grid may deviate substantially from paper to roof[20]. Point measurement cannot accurately depict areas of moisture inside a grid, hence it is possible to miss some roof penetration points.

It is also important that sufficient "contact time" is taken to get an appropriate reading. Reliable measurements are generally recorded in the range of 15 to 30 seconds.[21] The device must have time to penetrate the roofing system.

19 "What You Should Know About Nuclear Meters", Reprinted from Roofing/Siding/Insulation, Harcourt Brace Jovanovich Inc., (February 1980)

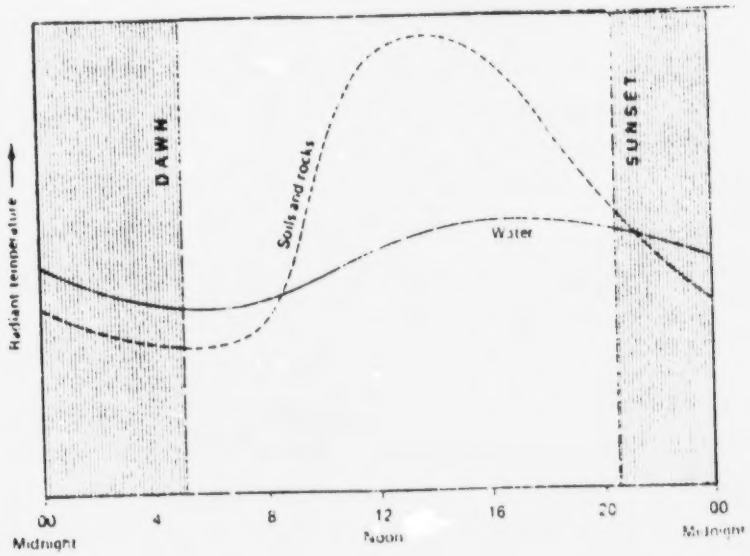
20 Everett, P., Personal Contact, Canada Public Works, (1982).

21 Ibid.

Thermal infrared instruments involve a sensing or camera like unit, and a display and/or recording unit. The display relies on tonal density to depict differing radiant surface temperatures. Data can be collected in either analogue or digital format. It is also possible to transfer analogue to digital format and vice versa, allowing for even more detailed analysis.

Thermography represents a substantial departure in equipment and methodology from either electrical capacitance or nuclear radioisotopic devices. The grid system is not used, since a full field image is recorded automatically. Complete roof coverage requires that these devices be operated from an oblique angle or a higher platform (e.g. cherry picker, airplane).

Thermal infrared scanning should be conducted at night or in early morning at the time of quasi-equilibrium conditions when the slopes of the temperature curves for the materials will be roughly constant, water will appear warmer than the surrounding materials and the effect of reflected light or shadows be substantially reduced. The following graph illustrates this phenomenon.[22]



22 Lillesand, T.H., and Kiefer, R.W., Remote Sensing and Image Interpretation, Toronto, John Wiley & Sons Ltd., p.403

In order for thermal infrared scanners to detect moisture, the surface temperature must be affected differently by dry and wet roofing materials. During the day the roof system accumulates heat from the sun, temperature anomalies could be indicative of varying surface albedo rates, extraneous localized heat sources as well as moisture content. Night reduces the number of uncontrolled variables and permits improved delineation of temperature anomalies, especially those associated with moisture.

Thermal infrared scanners do have problems. The instrument depends on heat flow from the roof. Roof temperatures consist of emitted and reflected radiation. There are a number of roof conditions and features other than water, which influence heat flow from the roof and could be misinterpreted. These conditions and features include ambient air temperature, wind speed, roof surface moisture, deck thickness, material thickness, supporting structures and sources of localized heat under the roof.

Other Techniques:

Nondestructive moisture metering methods are relatively new in the roofing industry. The whole idea of moisture metering is still in its infancy. There are other devices, in addition to those already mentioned, which show promise but are largely untested.

Microwave electrical capacitance moisture meter. The principles are the same as existing electrical capacitance instruments but utilizing a shorter wavelength.

Best results are found when the thickness and content of the specimen is known. Moisture meters of this variety have been used with erratic results, primarily due to the microwave system's propensity to reflect off roof ply interfaces.

Impulse radar is another instrument which has shown roof moisture metering potential. Although the system is cumbersome for field applications, it has been used with success in geophysical surveys. It uses short duration pulses which travel through roofing material; differences in travel time or in amplitude of various echoes are measured. The dielectric constant of the material can be calculated from these results.

Evaluation of Data Collected:

Moisture Content:

Moisture metering will tell you if the roof is wet, but just how wet is wet? Construction materials are never completely dry; even essentially dry materials contain some moisture. These materials, under different conditions, are subject to continuing ambient moisture fluctuations.

Normal roof moisture content varies with relative humidity. Relative humidities of 20, 20 to 45 and 45 percent plus are considered low, medium and high respectively.[23] Moisture content of certain materials of high relative humidities is illustrated in the following table:[24]

MOISTURE ABSORPTION AT HIGH RELATIVE HUMIDITIES

Roofing Material	Percent Moisture
Wood	16%
Lightweight Concrete	14%
Woodfibre Insulation	13%
Perlite Board	13%
Unsaturated Felt Sheet before Bitumen Impregnating	10%
Roofing Felt after Impregnating	4.5%
Fiberglass	1%
Cellular Insulation	0.1%

[23] Anderson, R., Analyzing Roofs: How Wet is Wet? Roofing/Siding/Insulation, (February 1976) p.2.

[24] Ibid, p.2.

It has been suggested that total moisture content, as well as moisture content above ambient levels, is important in determining when roof should be treated, repaired or replaced. Total moisture content describes material conditions where the structural characteristics are deemed treatable, repairable, replaceable. Moisture content above ambient level describes conditions where the roof contains moisture in addition to what is normally present. By implication, this is indicative of moisture invasion from other sources. Moisture content above ambient levels does not change when the material has to be replaced; it just relates moisture content to a fluctuating baseline dependent on environmental conditions. The existence of these 2 analytical perspectives emphasizes the importance of carefully evaluating moisture content information. The following table identifies the criteria used by Gammie Nuclear in the work performed for O.H.C.[25]

Material	Acceptable	Treat	Replace
Wood Fibreboard	0-25	25-45	45 +
Fiberglass	0-10	10-25	25 +
Lightweight Concrete	0-30	30-80	80 +
Perlite Board	0-20	20-35	35 +

Technique Assessment:

The National Bureau of Standards recently published a report dealing with the performance evaluation of the 3 most popular types of nondestructive moisture metering instruments. It was found that electrical capacitance, nuclear radioisotopic and infrared thermographic devices could detect threshold moisture of less than 10 percent

[25] Gammie, D., Personal Contact, Gammie Nuclear Service Co. Inc., (1982)

in 40 to 60 per cent of the cases.[26] Threshold moisture values less than 20 per cent were detected in 55 to 90 per cent of the cases.[27] Nuclear radioisotopic moisture metering devices were consistently more accurate than either electrical capacitance or thermal infrared instruments in predicting threshold moisture content below 10 and 20 per cent.[28]

Beyond threshold moisture content both the nuclear and thermal infrared devices were found to be more reliable than electrical capacitance equipment. It was also concluded that there was no significant difference between the ability of the nuclear and thermal infrared devices in detecting moisture beyond the threshold moisture content. In fairness to both the electrical capacitance and nuclear equipment tested, the thermal infrared assessment was constrained in that only one (1) unit was used and in limited applications.

The results of the National Bureau of Standards report have implied that the nuclear radioisotopic instrument is the most reliable system at low thresholds as well as beyond. However, this report did not include the less tangible aspects of roof moisture metering. The knowledge and skill of the required personnel was overlooked. Furthermore, the performance evaluation was based on two criteria only.

26 Knab, L., Mathey, R., Jenkins, D., Laboratory Evaluation of Nondestructive Methods to Measure Moisture in Built-up Roofing Systems, Centre for Building Technology, National Engineering Laboratory, National Bureau of Standards, Washington, DC, U.S.A. (January 1981) p.xiii

27 Ibid, p.xiii.

28 Ibid, p.xiii.

In the final analysis, the intangible elements remain important factors in roof moisture metering. Industry sources claim that all moisture metering methods are affected by poor environmental conditions on the roof. Ideally, moisture metering, of any variety, should be conducted in the spring and on a dry surface.

Cost of Techniques

The cost effectiveness of moisture metering should be intrinsic to the cost effectiveness of planned maintenance. The following figures will identify the relative costs of the three (3) commercially available moisture metering systems. Prices will depend a great deal on the nature of any given roof.

electrical capacitance	(app. 1981)[29]	12¢/ft^2 $1.29/m^2
nuclear radioisotopic	(app. 1981)[30]	11¢/ft^2 $1.18/m^2
thermal infrared	(app. 1981)[31]	3.5¢/ft^2* 38¢/m^2*

* Consultant cost not included, usually based on a flat rate.

It must be noted that these prices do not accurately reflect the infrared quote of 3.5¢/ft^2 (38¢/m^2); the real base costs are comparable for electrical capacitance, nuclear and thermal infrared moisture surveys. Pricing policies depend mainly on quantity of roof metered. All firms would require exact measurements and roof descriptions before accurate estimates will be given.

[29] Steeves, D.M., Personal Contact, A-Tech Canada, (1982)

[30] Gammie, D., Personal Contact, Gammie Nuclear Service Co. Inc., (1982)

[31] Bailey D., Personal Contact, Scanada Consultants Ltd. (1982)

Purchase:

The thermal infrared scanners and nuclear radioisotopic meters can be bought outright for $13,000.00 to $50,000.00 (Canadian 1982) and $5,000.00 to $9,000.00 (Canadian 1982) respectively.[32] Electrical capacitance equipment is usually marketed as a service, hence the purchase price of equipment is not often quoted. The benefit-cost of equipment purchase is dependent on the number of roofs scanned in any given year, staff expertise and the availability of facilities to carry out the task properly.

[32] Mill, P.A.D., et al., Manual: International Building Thermographic Training Course, Canada Public Works, Ottawa, Canada (1981)

APPENDIX VII

COST EFFECTIVENESS OF MOISTURE METERING

Moisture metering can provide qualitative and quantitative information on the extent of moisture content in the roofing system. Substantial savings through moisture metering can result when areas of good roof are exempted from total replacement. However, the cost savings generated through moisture metering must be put into perspective.

O.H.C.'s experience with moisture metering is largely based on nuclear radioisotopic analysis. A number of buildings in the metropolitan Toronto region were surveyed in 1976, using this technique. The cost savings attributable to moisture metering was calculated for a sample of these buildings, the results of which appear on the following page.

PROJECT AND ADDRESS	ACTUAL REPAIR YEAR	TOTAL COST OF WORK IN GIVEN YEAR	COST BASED ON REPLACED AREA ($/ft^2) 1976	ESTIMATED COST WHOLE ROOF ($/ft^2) (1976)	TOTAL EST. COST ROOF REPLACE (1976)	PER CENT SAVINGS (1976)
OH 63 Lumsden Ave.	76	$ 8,104.17	$ 0.55	$ 0.55	$25,631.94	68
OH 85 Gerrard St.	76	10,321.44	2.45	0.52	34,699.08	70
OH 85 Dundas St.	76	8,435.23	2.31	0.43	33,910.86	75
OH 34 Don Mount Ct.	76	30,803.93	10.34	0.87	60,202.26	49
OH 85 Parliament St.	76	8,800.92	5.36	0.77	19,933.44	56
OH 85 Parliament St.	76	8,496.92	2.36	0.74	19,933.44	57
OH 70 (1) McCowan Rd.	76	15,533.76	2.64	1.29	20,911.32	22
OH 116 Birchmount Rd.	76	9,093.37	4.54	0.80	19,820.34	54
OH 101 (A) Kingston Rd.	81	11,063.00	1.96	0.63	10,032.84	64
OH 101 (B) Kingston Rd.	81	14,254.00	2.09	0.42	10,205.10	76

PROJECT AND ADDRESS	ACTUAL REPAIR YEAR	TOTAL COST OF WORK IN GIVEN YEAR	COST BASED ON REPLACED AREA ($/ft^2) 1976	ESTIMATED COST WHOLE ROOF ($/ft^2) (1976)	TOTAL EST. COST ROOF REPLACE (1976)	PER CENT SAVINGS (1976)
OH 101 (C) Kingston Rd.	81	$16,554.00	$ 2.07	$ 0.44	$12,139.98	75
OH 101 (D) Kingston Rd.	81	17,659.00	2.05	0.45	12,886.44	74
OH 101 (E) Kingston Rd.	81	16,636.00	2.03	0.49	12,159.12	72
OH 101 (F) Kingston Rd.	81	17,947.00	2.04	0.47	12,735.06	73
OH 101 (G) Kingston Rd.	78	12,300.00	1.98	0.59	6,384.06	66
OH 70 (2) McCowan Rd.	79	32,878.00	1.98	0.57	20,422.38	67

The average cost of roof repair based on cost projections over the total roof area was 63¢/ft^2 in 1976. This figure compares favourably with the $1.74/ft^2 charged for roof replacement in the same year. The cost savings attributable to moisture metering in this sample was 65%.

The roofs (A - F) on Kingston Road were surveyed in 1976; repair in the form of wholesale replacement followed in 1981. The cost savings that could have been realized were not; consequently the roofs were replaced at a premium averaging 2.32/ft^2. In the event that roof maintenance had been carried out in 1976, the service lives of these roofs could have been prolonged and replacement deferred at a cost savings.

Note: Average cost for 1981 was $2.70 per ft^2. Therefore $2.32/ft^2 seems below the average for that year but still not as economical as repair work in 1976. The cost shown for roofs (A - F) at Kingston Road are best estimate of 1976 at $1.79/ft^2.

APPENDIX VIII

BASIC ROOF REQUIREMENTS:

It is beyond the scope of this study to take an inventory of the technical requirements of a roof, yet it remains important to emphasize the components of a good roof. Roofing problems apart from the neglect of these requirements usually originate when:[33]

a) the membrane experiences shrinkage compounded by poor perimeter edge securement and vertical adhesion between membrane, felt plys and insulation. This in turn creates slippage planes leading to premature membrane fractures.

b) concrete creep in substrate creates stresses and permanent deck deflection where water can pond, increasing the potential for membrane fracture.

c) deflection of precast concrete decks induces excessive strain on a membrane, as does the movement of these panels unless rigidly connected.

d) flexible steel decks cannot retain a bond to the vapour barrier or insulation, and this in turn can provide a slippage plane.

e) wet materials are used, thereby reducing the materials' capabilities to resist stress and in turn creating slippage planes at interplies.

f) incompatible materials and methods are used.

g) unqualified applicators not knowledgeable in water-proofing methods are used.

h) there is a failure to carry out appropriate/any roofing maintenance after completion of the roofing system.

[33] Ladner, F.E., "Roofing Design", The Canadian Architect, (March 1980), p.28.

In addition to these problems, others associated with frost action, bio-chemical deterioration, differential coefficients of expansion, roof traffic and roof accidents also have a bearing on roof performance. The basic requirements of a good roof then have evolved as responses to problems encountered. Victor Sobkowich identifies the basic requirements of a good roof in his article "Faulty Roofs Professional Liability", and these are as follows:[34]

i) roof decks should provide positive slopes to drains, i.e. at least 1:50.

ii) deck design and construction must permit good contact with the vapour barrier, insulation and roof membrane and allow for ongoing movement within the roofing assembly.

iii) adequate protection of the membrane must be provided whenever traffic is expected.

iv) expansion joints and control joints should be properly positioned so as not to impede roof drainage.

v) bituminous flashings with provision to enable their application to proper heights with adequate fastening facilities are essential at all curbs and walls.

vi) mechanical equipment should be at a minimum height of 14 inches (355 mm) above the membrane, and when equipment wider than 5 feet is in place, the minimum height above the membrane increases to 24 inches (610 mm).

[34] Sobkowich, Victor, "Faulty Roofs and Professional Liability", The Canadian Architect, (October 1977), p.53.

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